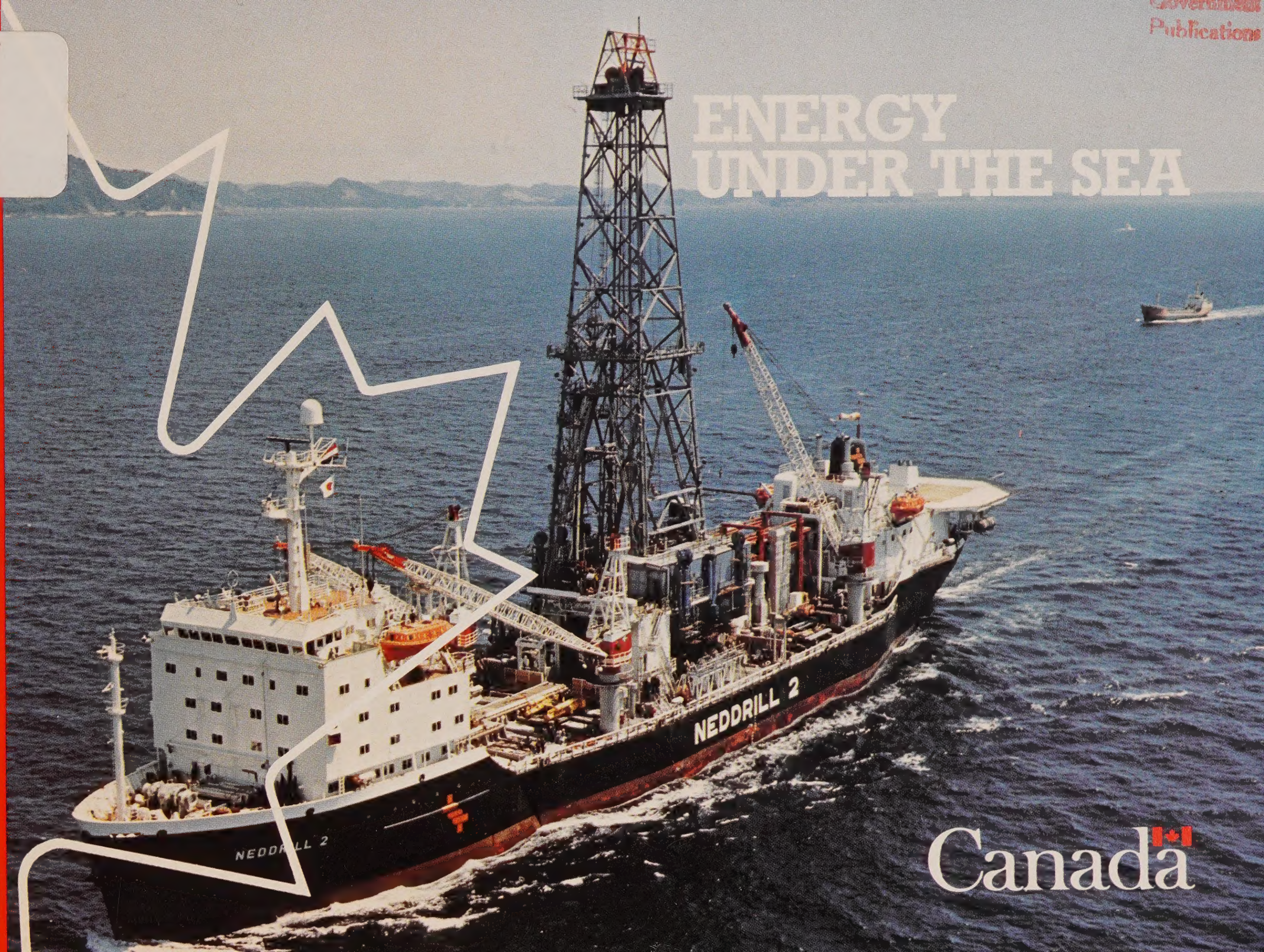
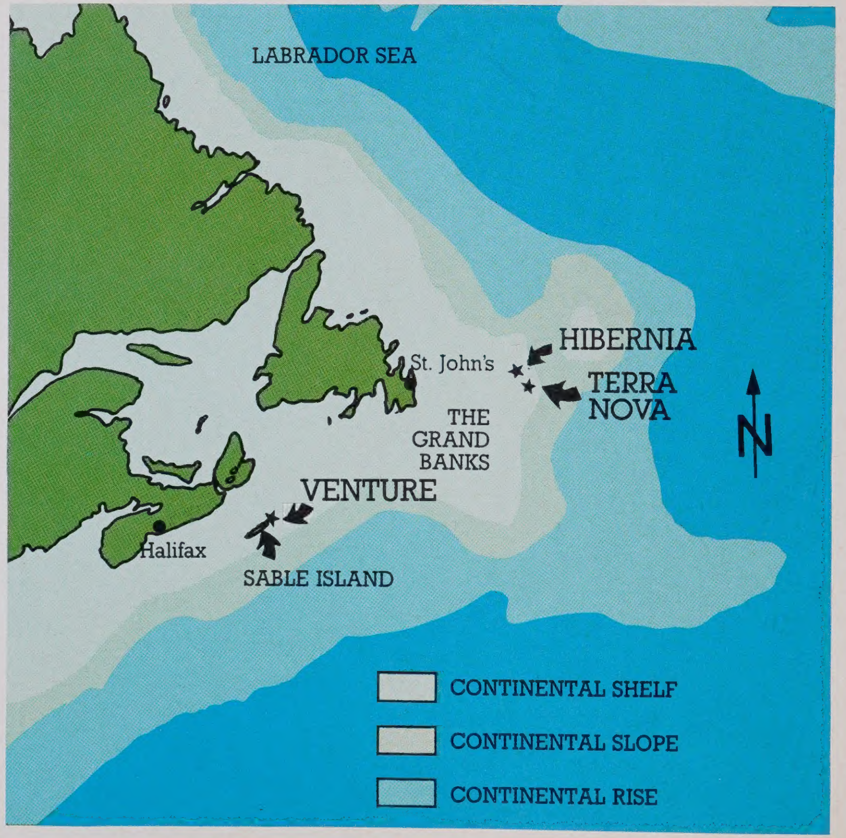
ENERGY UNDER THE SEA



Canada

Finding the first resource of Canada's Atlantic offshore was easy — or so John Cabot's crew said when they were back in Bristol. They claimed that the fish were so numerous on the Grand Banks in the summer of 1497 that they could be caught in weighted baskets lowered from the *Matthew*.

Finding the second resource wasn't as easy. The search had been on for almost 20 years and had cost almost $1 billion when in the summer of 1979 the drill of the *Glomar Atlantic* struck the oil-choked sandstones of Hibernia.



Front cover: The dynamically positioned drillship *Neddrill 2*. (*Neddrill photo*)

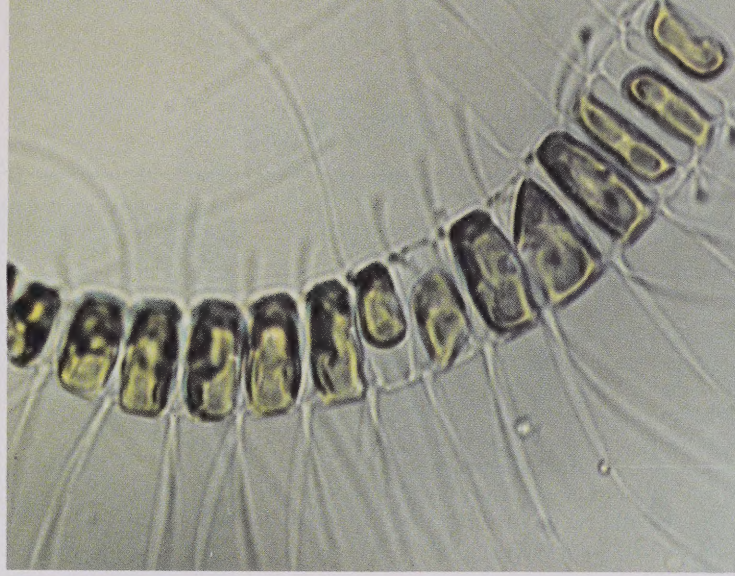
Back cover: The jack-up *Rowan Juneau* at work near Sable Island. (*Scott Films photo*)

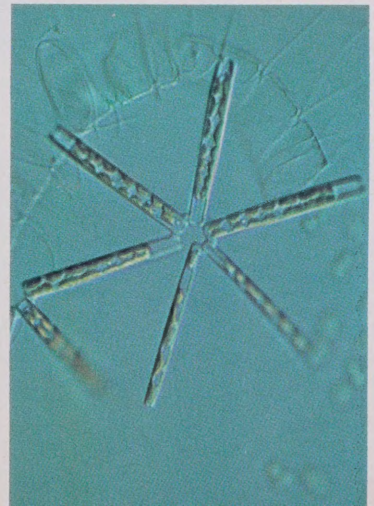
Stretching seaward as far as 500 km from Atlantic Canada is the submerged shoulder of North America, the continental shelf. It includes the Grand Banks of Newfoundland, Sable Island Bank and the other banks that have drawn fishermen for almost five centuries.

The seafloor of the shelf is flat and lies at depths of less than 500 m, most of it less than 200 m. It is covered by sand and mud, except where tides and currents are strong enough to sweep the bedrock clean.

Beyond the shelf are the continental slope and the continental rise. The three zones form what is called the continental margin.

Canada's Atlantic continental margin covers an area of almost 2.5 million square kilometres. It meets the muddy plains of the North Atlantic at distances as far as 1000 km from the coast and at depths of more than 4 km.





Phytoplankton are the 'grass' of the sea. Taking their energy from sunlight and their nourishment from the minerals dissolved in seawater, these tiny floating plants are the basic food that supports the chain of sea life.

In spring, when their numbers reach a peak, there can be 20 million organisms in a litre of seawater.

At right, three of the many plankton of the Atlantic coast. In the spring 'bloom' of phytoplankton, the numbers of *Chaetoceros* (top) reach their peak first, followed by *Thalassiothrix* (bottom left) and *Dinophysis* (bottom right). *(Bedford Institute photos)*

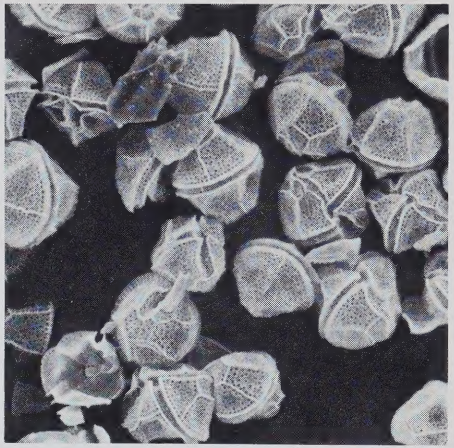
These organisms have an essential role in the fishery of Atlantic Canada. Their ancestors in the fertile sea of long ago had an essential role in the formation of the oil of Atlantic Canada.

Making oil and gas

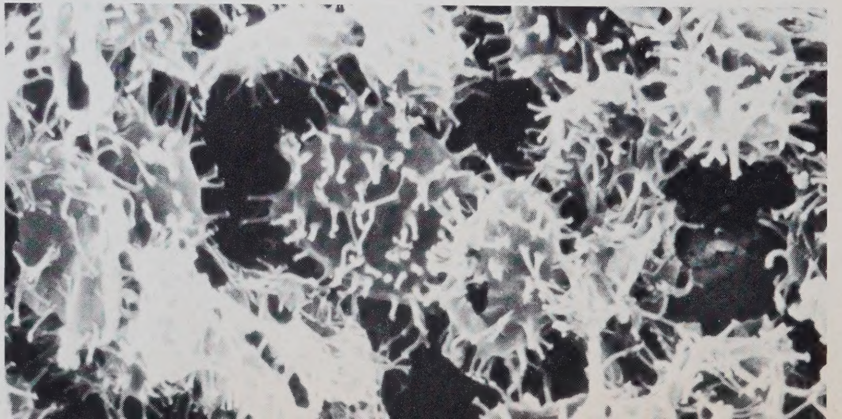
Mix your organic material

When the dinosaurs were roaming North America, life in the sea resembled life in the sea today. Although most of the animals and plants in the oceans at that time have since become extinct, they have been replaced by organisms of similar shapes and sizes. Then, as now, all sea life was based on the one-celled floating plants that need only sunlight, oxygen and nutrient salts to grow and multiply.

Each of the plants, and each of the animals that ate the plants, contained small quantities of lipids, natural oils that are one of the building blocks of life. We can't say for sure that these lipids were the source of the oil being found today, but we can say that there's a connection between the life of 150 million years ago and the petroleum of Canada's Atlantic offshore.



Modern plankton *Gonyaulax* (top), magnified approximately 250 times by an electron microscope. (*Bedford Institute photo*)



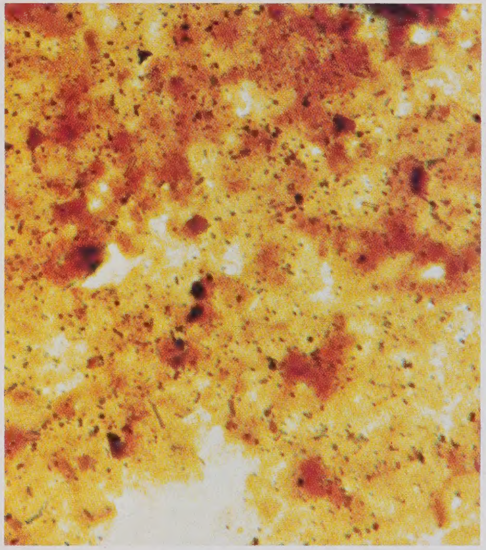
Fossil plankton *Apectodinium* (bottom), possibly an ancestor of the modern plankton. These fossils (an estimated 20 are in the photo) were found in shale samples recovered from a depth of 970 m in a well drilled in the Atlantic continental shelf. Magnified approximately 425 times. *(Bedford Institute photo)*

At that time the rivers of eastern Canada were carrying heavy loads of sediment down to the sea. Bits of the leaves and stems of land plants were also swept along, and were settling to the seafloor, accompanied by the bodies of animals and plants that had lived out their lives in the sea.

Much of the organic material rotted in the same way that it rots on land. Rotting requires oxygen, and in the surface layers of the ocean oxygen is usually plentiful. But the organic material that settled in water without dissolved oxygen underwent a different decay process with different chemical reactions.

Along the continental margin, thick deposits of sand and mud were accumulating. The ancestral St. Lawrence River was dropping heavy loads off the coasts of Nova Scotia and Newfoundland.

The organic material made up only a fraction of the volume of these sediments, but its presence in this oxygen-deficient environment satisfied the first of four requirements for the making of oil and gas fields.



Typical organic material of marine (oceanic) origin in rocks of the Atlantic continental shelf. Most of it consists of degraded remains of plankton. Under the right conditions, oil can be made from this mixture. Magnified 300 times. (*Bedford Institute photo*)

Typical organic material of land origin from the rocks of the Atlantic continental shelf. Most of the material consists of fragments of land plants that were washed into the sea. Ribbed fragments came from plant stems. Under the right conditions, natural gas can be made from this mixture. Researchers suspect that the black specks are charcoal, made by forest fires millions of years ago and washed into the sea. Magnified 300 times. (*Bedford Institute photo*)

Cook it, but not too much

As time passed and the deposits grew in thickness, the lower levels of the sands and muds began to consolidate, that is, to become cemented into sandstones and shales. Also, as they were separated from the cooling effect of seawater by more and more blankets of sediment, their temperatures increased. In some locations this increase was enough for what geologists call 'cooking' — the making of oil and natural gas from organic material. This was the second of the essential conditions for the making of oil and gas fields.

Some rocks produced more gas than oil, others more oil than gas. The proportions were determined by the cooking and the mix of organic material. In general, a little cooking produced gas, more cooking produced oil, while still more cooking produced gas again. Also, in general, organic material that originated on land was more likely to produce gas, while organic material that originated in the ocean was more likely to produce oil.

The oil at the Hibernia discovery on the Grand Banks originated in rocks whose organic material was mostly of oceanic origin — the plankton that were the ancestors of the plankton on the banks today. The gas at the Venture discovery near Sable Island originated in rocks whose organic material consisted mostly of fragments of land plants.

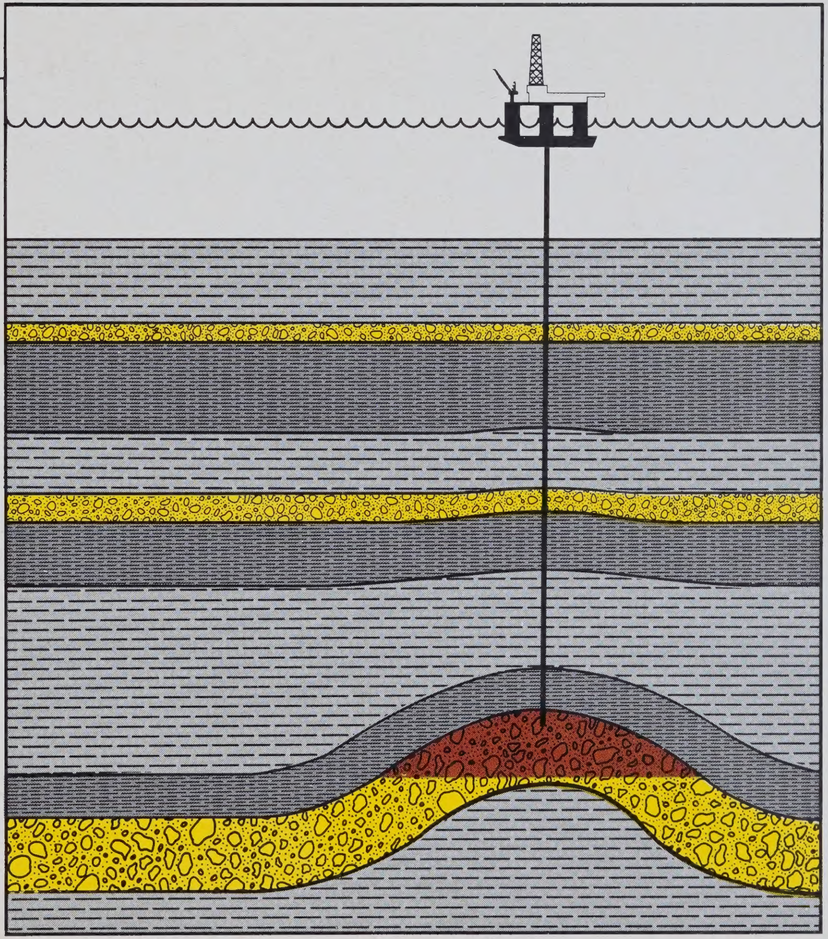
The coal of Nova Scotia, New Brunswick and Newfoundland is also of plant origin. But it came from plants that weren't broken up and washed into the sea. The plants grew, died and accumulated in the swamps of 290 million years ago. These deposits first became peat, and after being buried deep under later sediments, they became coal.

Let it rise

Because oil and natural gas are fluids, pressure may force them to move, usually toward the surface. Movement may be difficult in rocks with small spaces between the grains and no cracks, but in rocks with lots of space between the grains and lots of cracks it may be easy. If the gas and oil doesn't gather in a rock from which it can easily flow, it can't be recovered by drilling.

This kind of rock is called a reservoir. It is the third essential condition for the making of oil and gas fields. In the rocks of the Atlantic offshore, the thick sandstones deposited in the days of the dinosaurs are excellent reservoirs.

You might think that it would be handy to have the reservoir at the surface where it can be easily drilled. But if it were at the surface, the oil and gas would have escaped and been dispersed in the sea. This is one of the relentless processes of the earth's crust — oil and gas made at depth are slowly escaping and being dispersed.



Oil in a trap. Its escape upwards from the sandstone reservoir (yellow) is prevented by a seal of densely packed shale (grey).

But not too far

The escape of the oil and natural gas is prevented only if the top of the reservoir is sealed by a layer of rock that resists the passage of fluids. This seal is the fourth essential condition for the making of a field.

In the thick deposits of sandstone and shale of the Atlantic offshore the shale sometimes provides a seal for the sandstones. But only under special circumstances.

Most of the oil and gas has probably been able to find its way around the edges of the shale or through cracks in the shale. Only when the shale beds have been arched to form a blanket or dome over the sandstone reservoir has the shale been able to trap the oil and gas. These domes or blankets can be compared to upside-down bowls; they catch the rising oil and gas in the same way that a bowl catches falling rain.

Geologists use the word 'trap' for the combination of a reservoir rock with an upper surface that is domed or ridged and a sealing rock that keeps the oil and gas in a 'pool' that fills the cracks and spaces between the grains at the top of the reservoir. All oil and gas exploration starts with a search for traps.

The Bedford Institute of Oceanography in Dartmouth, Nova Scotia is the largest of the federal government's ocean research centres. Founded in 1962, the Institute brings together the marine scientists, hydrographic surveyors, technical staff and ships that are necessary for large-scale programs.

The Bedford Institute's *Hudson* (in photo) and the *Baffin* are more capable of long-range deep-ocean research than the vessels operated by any country except the U.S.S.R. (*Bedford Institute photo*)

Fog and ice, cod and oil

It's cold

In the Atlantic offshore, the petroleum industry must cope with conditions that are among the worst in the world. Although geological conditions under the seafloor in the Sable Island area resemble the conditions of the Louisiana offshore, working conditions at sea level are worlds apart. Even admitting the danger of hurricanes in the Gulf of Mexico, it's a millpond compared with the North Atlantic.

When people in the oil industry think of harsh conditions they usually think of the North Sea, where the industry has faced cold weather, high seas and frequent storms. Conditions on the Grand Banks are worse than in the North Sea. Storms are three times as frequent. Sea temperatures average six degrees lower. Air temperatures are five degrees lower on average over the year, with the result that the air temperature is below freezing 55 per cent of the time on the Grand Banks. In the North Sea, the air temperature is below freezing only 5 per cent of the time.

To single out just one effect of this temperature difference, anyone working on the Grand Banks during the cold months must be prepared for ice buildup caused by freezing spray. Generations of fishermen have had to deal with this problem, but the old solution of breaking ice from the rigging with mallets is dangerous and difficult. And freezing spray is just the beginning of the ice problems.

Small iceberg near St. John's. When they're the size of a small house they're called bergy bits; when the size of a grand piano they're called growlers. (*photo Bazeley, C-CORE*)

The Grand Banks area has two ice hazards that never occur in the North Sea: pack ice and icebergs.

Pack ice blocks the gulf of St. Lawrence and the Labrador coast in winter and can interfere with shipping in spring. On the Grand Banks there are years when pack ice is not a problem. But in other years ice floes are frequent; in 1985 ice covered the Hibernia area of the Banks from early January until May.

Icebergs are hazards to shipping mainly in spring and summer, from the eastern side of the Arctic Islands to the southeastern edge of the Grand Banks and occasionally farther south. The yearly average for the number of icebergs reaching the Banks is 300, but in a bad year there may be 2100. Small wonder the Labrador Sea is called Iceberg Alley. In one six-week period, the radar on a drillship operating off the Labrador coast picked up 391 icebergs within its 24 km radius.

Drillship *Pacnorse I* (above), which has operated in the Labrador Sea. In the thickest fog, you can't see the bow from the bridge. *(Petro-Canada photo)*

Breaking ice from the CSS *Dawson* (top left). (*Bedford Institute photo*)

Canadian Coast Guard icebreaker *Radisson* (lower left), based in Quebec City. (*Transport Canada photo*)

It's icy

Broken from the Greenland glaciers, these immense blocks of ice are preserved and transported by the cold currents of Baffin Bay and the Labrador Sea. While a small branch of the Labrador Current takes some icebergs into the Gulf of St. Lawrence, and another small branch takes some bergs within a few kilometres of St. John's, most bergs are swept around the eastern flank of the Grand Banks by the main branch of the current.

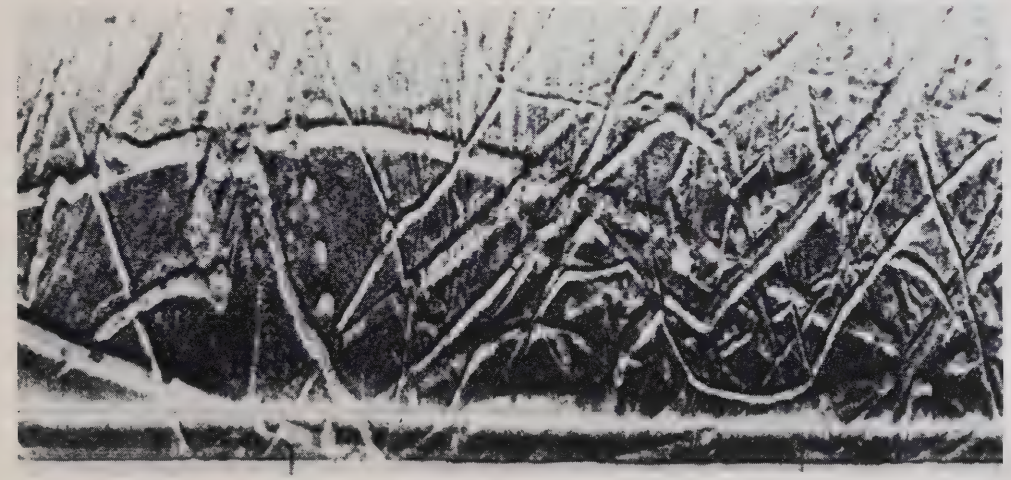
It's here that the Labrador Current collides with the warmer waters of the Gulf Stream and icebergs that may have been drifting for three years finally melt away.

Although winds on the part of the berg that is above water (its sail) may influence the direction in which it drifts, currents on the much larger area that is underwater (its keel) are usually the stronger influence. The keel of the larger bergs may reach depths of 200 m or more, but the height of the sail is usually less than a third of the depth of their keel.

Peak of giant berg is approximately 130 m above sea level — higher than a 35-storey building. Keel of berg is probably more than 500 m under water. Greenland ice cap, source of the berg, is on horizon. (*Bedford Institute photo*)

If a berg drifts aground on an area of the continental shelf that's covered with sand or mud, the keel leaves a mark. If a berg is dragged over the shelf, the keel leaves a furrow. After thousands of years of exposure to drifting icebergs, parts of the shelf off Newfoundland and Labrador have been repeatedly furrowed. Until recently the marks and furrows were only curiosities, but now they are being carefully studied in order to estimate the danger of icebergs to seafloor wellheads and pipelines.

Drifting icebergs endanger drillships in the Labrador Sea. Supply vessels lasso some bergs and divert them. *(Engineering, Memorial University photo)*



Sonograph provides a crude picture of the seafloor in 165 m of water on Saglek Bank in the Labrador Sea. Iceberg keels have made marks and furrows as deep as 3 m in the clay and silt. Depths of up to 17 m have been reported. *(Bedford Institute photo)*

It's an unlikely spot for a garden of the sea

To us, accustomed to the cycle of life on land, the productivity of the Atlantic offshore is startling. These waters, so often hostile to those who must remain on the surface, are gardens of life.

The first links in the chain of life are the plant plankton (phytoplankton). These microscopic one-celled plants obtain their energy from sunlight and use the mineral nutrients dissolved in seawater for growth and reproduction. Twice a year, in spring and fall, they get an abundance of what they need. Particularly in the spring, the growth in numbers can be explosive. The plankton are said to 'bloom', and the bloom may produce 20 million organisms in a litre of water. The sea may change colour (to green or brown) and seawater may be slimy to touch.

The spring bloom of the Atlantic offshore begins in late April or early May. It lasts 20 days at most. The first population explosion occurs among the numerous species of the plankton group called the diatoms, followed by the species of the dinoflagellate group.

Under ideal conditions, the plant plankton would smother the earth with their progeny in a matter of weeks. Luckily, ideal conditions never last that long. The growth in numbers is limited by the amounts of nutrients in the surface layers of the sea where sunlight can penetrate.

The dissolved nutrients are brought to the surface waters by the rivers flowing off the land and by the currents, tides and waves that swirl them up from the seafloor. But when conditions for plankton reproduction are good, the plankton use the nutrients faster than they are provided. The bloom runs out of some of its essentials, the rate of reproduction drastically declines and most of the plant plankton die off.

The seafloor near Hibernia. Starfish, sand dollars (5 cm diameter), worm burrows and shell debris. (*Bedford Institute photo*)

Surveillance of foreign fishing vessels on the Grand Banks from a Canadian Forces Sea King helicopter. (*Scott Films photo*)

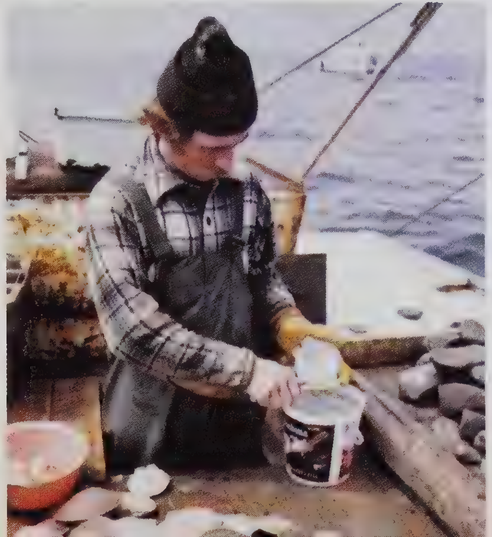
Feeding on the plant plankton the year round are a host of tiny animal plankton (zooplankton), the most numerous of which are the copepods, small relatives of the shrimps and lobsters. Feeding on the copepods are the smaller fish, the best known of which is the herring. And feeding on the smaller fish are the larger fish, notably cod, that sustain the fishery.

The chain of life in the Atlantic 150 million years ago provided the oil for which the offshore rigs are searching today. A mere 500 years ago that chain provided the cod that tempted European fishermen to cross the ocean in small wooden ships. Most of the fishermen now are Canadians, and in the offshore the days of small wooden ships are over. But the fertile waters are just as valuable today as in John Cabot's time. The chain of life must be protected.

During the exploration phase, the first phase of oil and gas activity in the offshore, the petroleum industry and the fishery have learned to live together. Indeed, they have cooperated in the establishment of communication systems and compensation arrangements.

As the next phase approaches, the phase of constructing production facilities and bringing the petroleum ashore, the federal government has adopted legislation for the regulation of oil and gas on Canada's frontier lands for the offshore and the North. The legislation drew from our experience and from the experiences of other countries where petroleum is in production and where the fishery conflicts have been resolved.

In February 1985, a new era began when the Atlantic Accord was signed by the governments of Canada and Newfoundland and Labrador. It created a new Canada-Newfoundland Offshore Petroleum Board and a positive environment for energy development to take place.



Inshore fishermen at cod trap off Torbay, Newfoundland (top). (*Fisheries and Oceans photo*)

Inshore fisherman from Tracadie, New Brunswick shucks scallops (bottom). (*Fisheries and Oceans photo*)

Two years later, the Canada-Newfoundland Atlantic Accord Implementation Act enshrined the Atlantic Accord into law. This legislation established a regime for joint management and revenue sharing for the exploration and development of petroleum resources in offshore Newfoundland and Labrador.

The Oil and Gas Production and Conservation Act, which was amended in 1987 when Parliament passed the Canada Petroleum Resources Act, provides environmental protection measures that are as good as any in the world. The first objective of the legislation is to ensure safety and to prevent accidents. There are also strict requirements for marine emergency responses, the cleanup of oil spills and debris, and the prompt payment of damages.

All companies drilling in the offshore have been required to post a security of $30 million to $40 million as a guarantee to pay promptly for damages from a spill or blowout without proof of negligence. The companies are also required to remove debris from the seafloor. If they don't, and if fishing gear or nets are damaged by the debris, the legislation provides for compensation and clears the way for out-of-court settlements.

Offshore fishing — *Cape La Have* out of Lunenburg, Nova Scotia on the Grand Banks in winter. (*Fisheries and Oceans photos*)

Minor disruptions to the fishery are unavoidable. Trawlers and oil rigs can't work in the same place at the same time. Sometimes the two industries compete for experienced employees, for onshore accommodations and for wharf space. But the federal and provincial governments are committed to the development of both industries with minimal disruption.

The petroleum industry helps the fishery and fishermen in many ways. More aircraft and vessels in the offshore provide a better search and rescue network. Meteorological information gathered by the oil and gas industry helps to provide more accurate forecasts. And the research on sea conditions and sea life that is required by legislation before petroleum exploration or production begins is providing a vast archive of data that is already helping the management of Canada's oceans and fish stocks.

The long search

The first permits for oil exploration in the Atlantic offshore were granted by the federal government in 1960. We knew next to nothing then about the geology of the continental margin. In return for exclusive rights to produce and sell the petroleum found in lands under permit to them, the oil companies had to agree in advance to the amount of exploration they would do. If they didn't live up to the agreement, the permits could be revoked.

The exploration system was successful in encouraging the companies to make a first assessment of the petroleum potential. Over the next 15 years, permits were granted for more than 1.3 million km^2. Some of these lands were as far as 720 km from the coast and in water depths as great as 4 km. After preliminary exploration, the petroleum industry gave up two thirds of its permits and concentrated on the more promising areas.

Hibernia discoverer, the drillship *Glomar Atlantic*. (*Chevron Standard photo*)

The first seismic surveys were conducted in 1960 by Mobil Oil Canada, Ltd. in the Sable Island area. Seismic surveys are the most useful of the petroleum industry's remote exploration tools. Using a technique similar to sonar, the seismic instruments record echoes from subsurface rock layers to provide a rough sketch of rock structures at depth. Seismic surveys cannot pinpoint oil and gas accumulations but they can reveal structures that might be traps. Only drilling reveals the full story.

Offshore drilling began in 1966 when Amoco Canada Petroleum Company Ltd. drilled two wells on the Grand Banks. They were the first of many disappointments. With the exception of a small discovery in 1973, the first 40 wells on the Grand Banks were dry. The best offshore drilling rig for the Banks has been the semisubmersible, a design that is particularly stable in high seas. Taking most of its buoyancy from its underwater pontoons, the semisubmersible floats *in* the water rather than *on* the water. Three semisubmersibles of the Sedco H type, built in the Halifax shipyards, accounted for more than half of the first 150 wells to be drilled in the Atlantic offshore. The *Sedco 709*, also built in Halifax, was the world's first dynamically positioned semisubmersible; it can maintain its position over a well in spite of currents and winds, without anchors, by means of a computer-directed system of thrusters. The first Canadian-owned semisubmersible was purchased in 1981 and named the *Bow Drill 1*. The fleet now includes *Bow Drill 2* and *Bow Drill 3*, the latter built in Saint John, New Brunswick.

The first major oilfield (discovery) in the Atlantic offshore was begun by a drillship and completed by a semisubmersible. The *Glomar Atlantic* drilled Hibernia P-15 in 1979. The tests for oil in the well were done later that year from the *Zapata Ugland*. On the northeastern edge of the Grand Banks, 320 km from St. John's, the well was drilled in 80 m of water to a total of 4407 m. Light

Bow Drill 1, the first Canadian-owned semisubmersible, in Halifax harbour. *(Bow Valley photo)*

crude oil was found in three sandstone zones. Although the Hibernia discovery was made by Chevron Standard Limited, the lands are under permit to Mobil Oil Canada. Mobil is in charge of operations in the field, with four partners, including Chevron Standard and Petro-Canada.

Petro-Canada made a second significant oil discovery in 1984 when the semisubmersible *Sedco 710* drilled the Terra Nova K-08 well off the coast of Newfoundland. The Terra Nova field is on the Grand Banks, approximately 350 km east of St. John's and 35 km southeast of the Hibernia discovery. Petro-Canada estimates that the Terra Nova field could contain between 11 million m^3 and 20 million m^3 of recoverable crude oil.

The exploration rights for the area in which the discovery was made are held by a group of companies: Petro-Canada, Canterra Energy Ltd., Mobil Oil Canada Ltd., Gulf Canada Resources Inc., ICG Resources Ltd., Trillium Exploration Corporation and PAREX.

In spite of the obvious ice hazards and a short drilling season, interest in exploration in the Labrador Sea was high, and it was encouraged in the early 1970s by several small gas discoveries. The first well off Labrador was drilled by the drillship *Typhoon* in 1971. In the late summer, with just a few days left in the drilling season, an iceberg drifted toward the ship. The crew of the drillship prepared to hoist anchors and move off the well to escape a collision. They were relieved to see the unpredictable berg drift past the ship, but then it changed direction and once more bore down on the *Typhoon*. This time they had to yield. The well was plugged, some anchors were hoisted but some anchor lines had to be cut. There wasn't enough time left in the season to reanchor and reenter the well. Two years later, drilling was resumed by the *Pélican*, the first of the dynamically positioned drillships.

Semisubmersible *Zapata Ugland* drilling on the Grand Banks. *(Scott Films photo)*

Developed in France with an eye to the special conditions of Iceberg Alley, dynamically positioned drillships are able to move off wells quickly when icebergs approach and to resume drilling soon after the danger has passed. Because the drilling season is only three months long, the companies operating off Labrador quickly adopted the dynamically positioned drillship as the preferred drilling rig. They are expensive to operate, but they save time. Support vessels can also save drilling time by pushing the smaller bergs away from the rigs; they even lasso bergs and divert them by towing. But some bergs are too big for easy towing, and sometimes there are just too many. In an average season, one third of the drillships in the Labrador Sea have to dodge a berg.

The story of drilling off Nova Scotia began with considerable excitement. The first offshore well in the Sable Island area, Shell Canada Limited's Onondaga E-84, found gas. And Sable Island E-48, drilled by Mobil and partners on the western tip of the island in 1971, found gas and some oil in quantities that seemed sufficient for production. News of the discovery caused a minor sensation, but the next seven wells revealed that E-48 had found a leaky trap, and reserves were not sufficient for production.

In 1979, the same year as the Hibernia discovery, the jack-up rig *Gulftide* chartered by Mobil, drilled Venture D-23, as part of a drilling program funded largely by Petro-Canada. Twelve kilometres off the eastern tip of Sable Island, this well provided the first confirmed evidence that gas could be produced from the Sable Island area. Drilled in 20 m of water, the well found gas in sandstones at depths down to 4954 m.

Jack-up rigs, unlike drillships and semisubmersibles, don't float (except when moving from well to well). A jack-up is basically a drilling barge with legs that are cranked down to the seafloor. Once the legs are firmly in place, the barge can be jacked up on the legs to provide a stable drilling platform above the waves. Although they are less expensive than drillships and semisubmersibles, jack-ups are not suitable for deep or ice-infested water, and their use off Canada has been restricted to the Gulf of St. Lawrence, the Bay of Fundy and the shallow waters near Sable Island.

Dynamically positioned drillship *Pacnorse I* in Labrador Sea in fog. (*Petro-Canada photo*)

A new generation of jack-up rigs was introduced in 1983. The *Glomar Labrador I* was chartered by Home Oil Company Limited and the *Rowan Gorilla I* was chartered by Bow Valley Husky (Bow Valley operated). These units are specially designed to withstand the severe Atlantic environment and to remain stable during the hypothetical storm that may occur once every hundred years in the area of Sable Island.

In the severe conditions of the Atlantic offshore, only the toughest of the world's offshore rigs can be used. More than handling heavy weather and ice and shifting sands, the rigs have to handle deep-drilling hardware. Their derricks have to hoist a string of drillpipe that is more than 5 km long. Some of the rigs have hoisted strings of pipe weighing more than 350 000 kg — equivalent to the weight of 300 automobiles — and they have done it at sea.

After more than 15 years, during which the petroleum industry operated successfully in Atlantic offshore conditions, the semisubmersible *Ocean Ranger* and her crew of 84 were lost in a storm on the morning of February 15, 1982.

Jack-up rig *Gulftide* drilled Venture discovery near Sable Island. (*Mobil photo*)

The *Ocean Ranger* was the biggest rig in the world, chosen because conditions on the Grand Banks are among the *worst* in the world. The stunning and sudden tragedy showed that, despite the very rapid evolution of offshore drilling technology since the 1950s, we still have a great deal to learn about operating in the severe Atlantic offshore conditions. It indicated the need for caution and extreme vigilance in all further offshore development activity.

Governments and industry began a broad reexamination of the techniques and safeguards of offshore development. Thorough study of all aspects of the sinking has provided a new understanding of the challenges technology and people must face in the offshore. To the fullest extent possible, the painful lessons learned from the *Ocean Ranger* are being used to provide greater security for those who work offshore. Government and industry together are establishing the highest possible standards for training of offshore personnel and developing the best evacuation systems.

The two pieces of federal legislation that provide the framework for petroleum exploration and production on Canada's frontier lands are the Canada Petroleum Resources Act and the Oil and Gas Production and Conservation Act.

To oversee and administer the legislation, the Canada Oil and Gas Lands Administration (COGLA), was established in conjunction with the passage of the Canada Oil and Gas Act, by a memorandum of understanding between the ministers of Indian Affairs and Northern Development and Energy, Mines and Resources.

In 1987, the Government of Canada passed the Canada Petroleum Resources Act, which replaced the Canada Oil and Gas Act, and amended the Oil and Gas Production and Conservation Act. This new act brought into law the government's Frontier Energy Policy.

COGLA's responsibilities include

- authorizing all proposed oil and gas exploration activity, and establishing terms and conditions before industry proceeds;
- regular inspections of all operations; and
- requiring companies engaged in the search for oil and gas to undertake site-specific environmental studies and to submit detailed contingency plans that outline precisely the response that would be made in the event of a blowout or similar mishap.

On February 11, 1985, the Government of Canada and the Government of Newfoundland signed the Atlantic Accord for joint management and revenue sharing in the area offshore Newfoundland. This has led, through the Canada-Newfoundland Atlantic Accord Implementation Act, to the establishment of the Canada-Newfoundland Offshore Petroleum Board. The board inherits COGLA's operational responsibilities for the Newfoundland offshore.

The federal and Nova Scotia governments agreed in 1982 to establish a joint Canada-Nova Scotia oil and gas board to supervise COGLA's administration of the offshore area of that province. The board, and other terms of the 1982 agreement, were formally established by legislation in 1984.

On August 26, 1986 the governments of Canada and of Nova Scotia signed the Canada - Nova Scotia Offshore Petroleum Resources Accord. This accord replaced the 1982 Canada - Nova Scotia Agreement on Offshore Oil and Gas Resource Management and Revenue Sharing. The 1986 agreement included the establishment of a new independent Canada - Nova Scotia Offshore Oil and Gas Board to administer and regulate all aspects of offshore oil and gas activities. The legislation governing the Nova Scotia offshore is called the Canada - Nova Scotia Offshore Petroleum Resources Accord Implementation Act.

To ensure continuity and stability for the petroleum industry operating on the east coast, the Canada-Newfoundland Atlantic Accord Implementation Act and the Canada - Nova Scotia Offshore Petroleum Resources Accord Implementation Act incorporate the provisions of both the Canada Petroleum Resources Act and the Oil and Gas Production and Conservation Act, and their respective regulations.

The Preferred Orientation and Displacement (PROD) lifeboat launching system was developed through government-industry cooperation. The system is an add-on device that moves a lifecraft out and away from an offshore drilling unit during an emergency. It minimizes the risk of collision between the lifecraft and the drilling rig. The PROD system has been installed on the Husky/Bow Valley semisubmersible drilling unit *Bow Drill 3*.

Getting it ashore

In the 1980s, we know much more about petroleum in the Atlantic offshore than we knew in the 1960s when exploration began. After many disappointments, we've had some good news. But we're still in the preliminary stage of discovering the oil and gas fields. Moreover, we don't yet have all the answers about existing discoveries, how they will be developed and how the oil and gas will be brought ashore.

The development of offshore fields involves three major stages: drilling production wells; installing production equipment that brings the petroleum to the surface and removes impurities; and installing a transportation system to take the gas to markets and the crude oil to refineries.

Production in the Canadian offshore will require a selection of the most recent methods and the toughest tools that have been developed for other hostile environments. And it will require new methods and tools for unique conditions.

The construction of production facilities will be the largest project ever undertaken in Atlantic Canada. The challenges for designers, engineers, project managers, supply firms, manufacturers and shipyards will be immense.

By looking at how other offshore fields have been developed, we can get an idea of the range of production options. But we have to remember that for important parts of the Atlantic offshore no wellhead installation, no production installation and no transportation system can even be considered if it can't cope with ice.

Night view of a steel accomodation platform and supply vessel in the Frigg gas field. Frigg platforms stand in 100 m of water. (*Elf Aquitaine photo*)

How they do it at Frigg

Frigg, a giant gas field that straddles the boundary between the Norwegian and British sectors of the North Sea, was developed at a cost of more than $3 billion. In 1977, six years after its discovery, the first gas from Frigg's reserves of 270 billion m^3 reached shore. At full flow, the field supplies about 5 per cent of the energy needs of the United Kingdom.

Two main types of production platforms have been used in the North Sea. Frigg has two steel platforms and three concrete platforms.

Accommodations for the crew are supported on a steel platform. If it stood on land, where the whole platform could be seen, this platform would resemble an electrical transmission tower as high as a 33-storey building with a hotel perched on top. And on top of the hotel is a heliport and a communications mast. One of the Frigg drilling platforms is also supported by steel; there is more steel in this frame than in the Eiffel Tower.

The Frigg field steel accommodation platform (right) connects by bridge to treatment platform supported by two concrete legs (left). Just behind these legs can be seen the three legs that support the other treatment platform. (*Elf Aquitaine photo*)

How they do it at Statfjord

More than 90 per cent of the world's offshore petroleum platforms are supported by similar steel skeletons, usually called jackets. The jackets are held in place by piles in the seafloor.

The other major platform type, the concrete platform, was developed for the North Sea fields. Weighing 20 times more than steel platforms (and costing more than three times as much), they don't need to be fastened to the seafloor; their own weight keeps them in place. For this reason they are usually called concrete gravity platforms. While steel platforms support the weight of their above-water facilities on steel skeletons, concrete platforms support the weight on clusters of concrete silos or cells. Some of the cells are bigger than others, some are higher than others, some rest on the seafloor, some reach above water, some are filled with air, some are filled with water and some are used to store oil.

The two treatment platforms and one of the drilling platforms at Frigg are of concrete. The concrete drilling platform resembles a giant tower fortress, but in fact it is made up of concrete silos and cells. The treatment platforms consist of a cluster of concrete silos, sprouting tall, hollow concrete legs that reach above water and support several levels of decks containing the treatment equipment.

Some of the impurities in the natural gas that flows up from the Frigg wells are removed on the drilling platforms, the remainder are removed on the treatment platforms. Pipelines take the gas from the 'reatment platforms to Scotland, 360 km away. The pipelines are buried in the sand and mud of the seafloor and are further protected against damage from ships' anchors and trawlboards by a concrete coating.

Another giant field on the Norwegian - United Kingdom boundary is the North Sea's largest oilfield, Statfjord. About 84 per cent of the field is in the Norwegian sector and the reserves are estimated to be so large they could supply Norway's petroleum needs for half a century. In addition to 520 million m^3 of oil, Statfjord has an estimated 96 billion m^3 of natural gas.

Three concrete platforms, the largest offshore structures ever built, have been installed. Statfjord A was towed out from its construction site in a Norwegian fjord and lowered on the field in 1977. It began production in 1979. Statfjord B was towed out and installed in 1981. The total weight of Statfjord B (including water used as ballast in its concrete cells) is 800 000 t. In appearance the Statfjord platforms resemble the Frigg treatment platforms, with concrete cells on the seafloor and tall concrete legs rising above water to support the decks. But at Statfjord, each platform is an independent production centre, where wells can be drilled, impurities in the oil can be removed, and the crew can be housed and fed.

Statfjord A cost $1.5 billion. It is as high as a 60-storey building. It has a six-storey hotel on its top deck where the 200 crew members eat, sleep, watch movies and keep in shape in specially equipped exercise rooms.

Statfjord B cost $2 billion. Tougher safety and environmental protection regulations were responsible for part of the increased cost.

Statfjord C was towed out and installed during the summer of 1985. In the late summer of 1985, Mobil Oil and its partners announced their preference for the construction of a concrete production platform, similar to the Statfjord installations, for the Hibernia offshore oil field.

Cluster of cells at base of Statfjord B under construction. Four cells were built to a height of 175 m and became platform legs. The rest were sealed at 64 m for ballast and storage. (*Statoil photo*)

Statfjord B tow-out from Norwegian coast. Production facilities (and white seven-storey hotel for crew) are supported on four concrete legs. (*Statoil photo*)

On the platform decks, impurities are removed from the crude oil before it is stored in the cells in the bottoms of the platforms. Periodically the oil is transferred to tankers for delivery to refineries on shore. One of the impurities removed from the crude oil is dissolved natural gas. The gas is being reinjected into the reservoirs until a pipeline is built to shore. The gas would be wasted if it were not reinjected.

One of the advantages of concrete platforms for Statfjord was that Norwegian workers and Norwegian companies participated in the massive construction projects. If steel platforms had been built, the construction jobs would have been mostly for highly skilled steel workers and the material requirements would have included imported steel. The concrete platforms, though they also needed steel, required more materials that were available locally, and the work could be spread among more people, many of whom didn't need to be highly trained. Three hundred and fifty firms participated in Statfjord A's construction and installation, and 21 million hours of work were generated.

How they do it at Argyll

The Argyll field in the North Sea was the first field to use a floating production platform. Floating platforms are an option being considered in the Atlantic offshore because they can be built and installed faster than fixed platforms.

It was decided in 1973 to produce Argyll from a semisubmersible, and by 1975 the first oil was delivered to shore by a tanker. The development had taken half the time and one third the investment of a comparable fixed platform.

Weather interrupts production on Argyll several times a year. In bad weather, the tanker slips its mooring, the pipes from the wells on the seafloor to the semisubmersible can be disconnected, and production ceases until conditions improve.

In 1976, in a storm so severe it could be expected only once in 50 years, three of the semisubmersible's 12 anchor chains broke, and it drifted 200 m off location. This indicates the technological challenges designers will face in the Atlantic offshore.

How they do it at Garoupa

Brazil's Garoupa field used a converted tanker as a floating production platform until a fixed platform was installed. Crude oil flowed in pipes from the seafloor wellheads to the production tanker moored in 150 m of water; the dissolved gas was removed; and purified crude was stored in the tanker until it was transferred to a sister tanker for delivery to refineries on shore.

The Brazilian state oil company, PETROBRAS Mineraçao S.A., intends to use the two tankers for early productions from another field.

Argyll's floating production platform in dock for servicing. (*Hamilton Bros. photo*)

Canadian Coast Guard ship *Grenfell* (top), an offshore supply vessel converted for search and rescue, in Corner Brook harbour. (*Transport Canada photo*)

Buoy tending from CCGS *Wolfe* (bottom) near Charlottetown, P.E.I. (*Transport Canada photo*)

Federal fisheries patrol vessel *Chebucto* alongside Russian trawler on the Grand Banks. (*Scott Films photo*)

The Bedford Institute's *Baffin* (top) on hydrographic survey off Labrador. (*Bedford Institute photo*)

Vessel Traffic Management (VTM) Centre at Argentia, Newfoundland (bottom) directs traffic in busy Placentia Bay. (*Transport Canada photo*)

What of the future?

The discoveries made in the Atlantic offshore may yet bring considerable benefits to the residents of Atlantic Canada. Energy supplies from future offshore development can lessen Atlantic Canada's dependence on oil imports. This means moving from the exploration phase to the production stage. We will take this step as the petroleum industry experiences a more favorable and stable economic climate, making development of Hibernia and the other Atlantic offshore discoveries economically attractive.

By any standard, Hibernia is a major discovery. It and the other finds in the Atlantic offshore can make a significant contribution to Canada's future oil and gas supplies. The challenge for all those involved in petroleum development is to take full advantage of these long-term opportunities provided by energy under the sea.

Published under the authority of
the Minister of Energy, Mines and Resources.

Copies of *Energy under the Sea* are
available at no charge from:

Energy, Mines and Resources Canada
215 Water Street
Suite 301
St. John's, Newfoundland
A1C 6C9

and

Energy, Mines and Resources Canada
5151 George Street
Room 503
Halifax, Nova Scotia
B3J 1M5

Aussi disponible en français

Cat. No. M27-39/1988 E
ISBN 0-662-14321-3

Energy, Mines and Resources Canada
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